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Research Article

Sesame Yield Response to Deficit Irrigation and Water Application Techniques in Irrigated Agriculture, Ethiopia

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The study was conducted at Werer Agricultural Research Center, Addis Ababa, for two years, 2013 and 2015, during main seasons and for three years, 2012/13, 2013/14, and 2014/15, during the cool period cropping season (November to February) as in the local cropping calendar. The study was aimed at identifying optimum soil moisture stress for sesame and thereby determining appropriate water-saving irrigation methods and also productivity under limited water resource conditions. Nine treatments with three levels of irrigation water percentage based on evapotranspiration of the crop (ETc) (100% ETc, 75% ETc, and 50% ETc) and three types of furrow irrigation methods (alternate furrow, fixed furrow, and conventional furrow) were used. The study design was randomized complete block design (RCBD) with three replications. The yield of sesame had significant ($p < 0.05$) variation among treatments due to deficit irrigation levels and application methods for sesame planted in main seasons. The highest mean yield of 937.50 kg/ha and 2797.6 kg/ha was obtained from the treatment of 50% ETc with alternate and conventional furrow application methods in 2013 and 2015, respectively. The combined mean yield of two years (2013–2015) showed different levels of deficit irrigation, and irrigation methods had a significant effect ($p < 0.05$) on main season planted sesame. Hence, the highest mean yield of 1846.7 kg/ha was obtained from the application of 50% ETc with the conventional furrow application method. In the cool planting season, the highest mean yield of 528.55 kg/ha, 1432.3 kg/ha, and 1562.5 kg/ha was obtained from treatments of 50% ETc, 75% ETc, and 100% ETc with the conventional furrow application method in 2012/13, 2013/14, and 2014/15, respectively. Moreover, during the same period over years, combined analysis showed that the highest mean yield of 1053 kg/ha was obtained from application of 100% ETc with the conventional furrow application method. Thus, it is concluded that a deficit irrigation treatment of 50% ETc with the conventional furrow application method for main season and application of 100% ETc with the conventional furrow application method for cool planting season are best practices of water-saving strategies for irrigated agriculture system.

1. Introduction

Globally, more than 40% of annual food production comes from irrigated land, and agriculture is the largest consumer of water, at 70% of all freshwater withdrawals [1]. As water scarcity becomes more acute in many parts of the world, increasing the effectiveness with which agricultural water resources are used is a priority for enhanced food security of water [2]. In addition to this, climate change will affect the extent and productivity of both irrigated and rainfed agriculture across the globe, increasing crop water demand and decreasing crop productivity in many regions [3]. Renewable water resources for the whole of Africa amount to about 3930 km^3 or less than 9 percent of global renewable resources [4].

Water supply is often the most critical factor limiting crop growth and yield in rainfed areas and the most expensive input of irrigated crops [5]. In the dry areas, agriculture accounts for about 80% of the total consumption of water [6]. Therefore, crop production usually requires maximizing yields on limited available water resources [7]. Regardless of the irrigation potential and water availability, small area has been grown under irrigation on state farms at lower elevations [5].

In the semiarid areas of Ethiopia, water is the most limiting factor for crop production where the amount and distribution of rainfall is not sufficient to sustain crop growth and development; an alternative approach is to make use of the rivers and underground water for irrigation [6]. Based on the total irrigated area, cropping pattern, and calendar, annual agricultural water withdrawal was estimated to be in the order of 5200 million m^3 in 2002, and the number increased in 2016 so that in Ethiopia, agricultural water withdrawal is estimated at around 9000 million m^3 [4].

Studies have shown that deficit irrigation significantly increased grain yield, ET, and WUE as compared to rainfed winter wheat [7]. However, this approach requires precise knowledge of crop response to water as drought tolerance varies considerably by growth stage, species, and cultivars. The practice of limiting water applications to drought-sensitive growth stages aims at maximizing water productivity and stabilizing, rather than maximizing, yields [8]. Even a single irrigation omission during one of the sensitive growth stages caused up to 40% grain yield losses during dry years [9]. Sesame yield was reduced by up to 6.42% when the number of irrigations was reduced from seven to five [10]. According to Oweis [8], sesame crop was affected by water deficiency and was subjected to drought stress during flowering stage and grain filling stage.

Sesame seed has a long history of use for its oil as well as for other food products such as bread and bakery items. Approximately 70% of worldwide seed production is processed into oil and meal [11] as cited by USDA plant guide. Growing drought-tolerant crops as a useful strategy in many situations and efficient use of limited water are considered [12]. Sesame is a very important crop with drought-resistant characteristics and suitable for cultivation in semiarid areas than other crops. In sesame, like other crops, grain filling period is of great importance in determining productivity. Although the grain filling period is influenced by plant genetics, environmental stresses such as drought can cause yield loss [13].

This study was carried out at the Werer Research Center with the objectives to identify the level of deficit irrigation with the combination of application methods that allow achieving optimum sesame yield and its relation with WUE to develop effective water techniques for the efficient use of irrigation water in irrigated agriculture as a means of water-saving strategies under semiarid conditions.

2. Materials and Methods

2.1. Experimental Design. The experiment was laid out in RCBD with three replications. Nine treatments, with three irrigation amounts (100%, 75%, and 50% ETc) and three irrigation methods (conventional, alternative, and fixed), were tested in an experimental plot of 5 m × 10 m. Sesame Adi variety (*Sesamum indicum*) seeds were sown manually in double rows on ridges that are 80 cm apart, with row spacing of 40 cm and plant spacing of 10 cm. The size of each plot was 10 m × 5 m and was separated from adjacent plots within the replicates by 0.5 m in addition to 0.3 m bund. The field experimentation involved deficit irrigation treatments at fixed frequency (recommended amount and interval is 100 mm every twenty-one days) and different irrigation amounts and irrigation methods.

2.2. Irrigation Treatments. The treatments consisted of three irrigation methods, viz, alternate furrow irrigation (AFI), fixed furrow irrigation (FFI), and conventional furrow irrigation (CFI) and three levels of irrigation applications (50% ETc, 75% ETc, and 100% ETc) as indicated in Table 1.

2.3. Irrigation Water Application. Establishment irrigation (as preirrigation of 150 mm) was given for all plots after planting two times. Irrigation application events were monitored through soil moisture readings. Irrigation depths (amount of water applied) were calculated through cumulative ETc values in a given period, and plots were replenished with 100%, 75%, and 50% of cumulative ETc as per the treatment to be applied. Measured amount of irrigation water was applied by using a two-inch Parshall flume.

2.4. Water Use Efficiency (WUE). Sesame yield was determined by counting randomly selected plants in each plot at maturity stage from a 50 m^2 plot, which were then harvested and threshed for grain yield determination. Actual grain yield was determined on a 12.5% moisture basis. The grain weight was used for calculating the WUE. The water use efficiency (kg/ha-mm) was calculated as stated by Sinclair et al. [14]: it is ratio of the total biomass or grain yield to water supply or evapotranspiration or transpiration on a daily or seasonal basis:

$$\mathrm{WUE} = \frac{Y}{\mathrm{ET}}, \tag{1}$$

where WUE is the water use efficiency (kg/ha-mm), Y is the yield (kg ha^{-1}), and ET is the evapotranspiration (mm).

2.5. Statistical Analysis. Analysis of variance (ANOVA) was performed using the general linear model procedure in SAS version 9.0 with appropriate error terms. The least significant differences at a probability level of 0.05 were calculated for mean comparisons.

3. Results and Discussion

3.1. Grain Yield. The results in Table 2 indicate that sesame yield was significantly affected by irrigation levels and application method during both main cropping and cool cropping seasons. In experiment years from 2013 to 2015, the result indicated that the grain yield was significantly affected by irrigation depth applied during the main planting season (Table 2). Therefore, a high grain yield (937.50 kg/ha) was produced from T3 (irrigation amount of 50% ETc at all growth stages with the alternate furrow application method), which provided 50 mm of irrigation water every ten days, and a grain yield of 2797.6 kg/ha was obtained from T9, which was 50% ETc applied at growth stages with the conventional furrow application method. Also, in the same

Table 1: Treatment combinations.

Irrigation amount	Treatments		
	Alternative	Fixed	Conventional
100% ETc	T1	T4	T7
75% ETc	T2	T5	T8
50% ETc	T3	T6	T9

Table 2: Sesame yield response to deficit irrigation during the main cropping season in 2013 and 2015.

Irrigation depths	Irrigation methods			Mean
	Alternate furrow	Fixed furrow	Conventional furrow	
Yield (kg/ha) response to irrigation amount and methods during the main cropping season in 2013				
100% ETc	895.83[ba]	916.67[a]	875.00[ba]	895.83
75% ETc	708.33[b]	770.83[ba]	916.67[a]	798.61[b]
50% ETc	937.50[a]	833.33[ba]	895.83[ba]	888.88
Mean	847.22	840.28	895.83	861.11
CV%		13.22		
R-square		0.5		
$LSD_{0.05}$	Irrigation method	Irrigation depth	Method ∗ depth	
	NS	**	**	
Yield (kg/ha) response to irrigation amount and methods during the main cropping season in 2015				
100% ETc	2142.9[a]	2529.8[a]	2559.5[a]	2410.733
75% ETc	2172.6[a]	2619.1[a]	2648.8[a]	2480.17[a]
50% ETc	2202.4[a]	2232.1[a]	2797.6[a]	2410.7
Mean	2172.633	2460.33	2668.63	2433.87
CV%		16.69		
R-square		0.46		
$LSD_{0.05}$	Irrigation method	Irrigation depth	Method ∗ depth	
	NS	NS	NS	

cropping season, a minimum yield (708.33 kg/ha) was obtained from treatment T2, which was irrigated with 75% ETc at all growth stages with the alternate furrow method, and 2142.9 kg/ha was harvested from T1, which was irrigated with 100% ETc at all growth stages with the alternate application method (Table 2). Hence, the results showed that sesame yield was significantly affected by the amount of irrigation water applied and its application method with a yield advantage over 100% ETc (Table 2). Studies show that sesame yield was reduced by up to 6.42% when the number of irrigations was reduced from seven to five irrigations [9]. The yield of sesame was affected by water deficiency and the yield decreases considerably, when a crop was subjected to drought stress during flowering stage and grain filling stage [15]. This indicated that grain yield of sesame decreases with decreasing water amount.

Combined over years analysis indicated that sesame grain yield was significantly ($p < 0.05$) affected by the amount of irrigated water applied during the main cropping season. In this study, sesame plants were irrigated with 100 mm, 75 mm, and 50 mm of water every ten days for three years (2012/13–2014/15) during the main cropping season and for two years during the main planting period. From this, the maximum mean sesame grain yield (1846.7 kg/ha) was obtained from the treatment of 100% ETc with the conventional furrow application method during the main season (Table 3). This was probably associated with water availability during grain filling and establishment (preirrigation of 125 mm) that was applied with no stress at all growth stages. Increasing irrigation water application between irrigation frequency and amount of water to crop decreased yield and plant growth [15]. In the same experimental season, a minimum mean sesame grain yield (1440.5 kg/ha) was harvested with the treatment of 75% ETc at all growth stages with the alternative furrow application method, which is 21.99% yield difference from full irrigation applied treatment (Table 3). According to Tantawy et al. [9], sesame yield was reduced by up to 6.42% when the number of irrigations was reduced from seven to five irrigations. Fereres and Soriano [16] stated that the level of irrigation supply under deficit irrigation permits achieving 60–100% of full evapotranspiration.

The sesame yield during the cool planting season of the experiment period 2013–2015 obtained maximum yield of 1562.5 kg/ha was harvested from T7 (full irrigation at all growth stages with the conventional furrow application method), which was irrigated with 625 mm of water during the growth period including 125 mm preirrigation (Table 4). During experiment period 2012/13, 2013/14, and 2014/15, the maximum mean sesame grain yield was obtained: 528.55 kg/ha, 1276.0 kg/ha, and 1562.5 kg/ha, which were associated with 50% ETc, 100% ETc, and the conventional furrow application method, respectively (Table 5). Research studies show that the practice of limiting water applications to drought-sensitive growth stages aims at maximizing water productivity and stabilizing, rather than maximizing, yields [17]. These expressions can also be used to estimate the range of water use within which deficit irrigation would be more profitable than full irrigation [18]. This shows the potential in alleviating the adverse effects of unfavorable rain patterns, which improves and stabilizes crop yields [6]. Also, this study shows that the minimum amount of irrigation water had an advantage over full amount of irrigation with a significant difference among treatments in the sesame grain yield (Table 5).

In the experiment year 2013, the result indicated that irrigation water significantly affects sesame yield with the method of application during the growing period which saved water up to 50% with a 20% yield increase over a full irrigation (100% ETc) with the conventional method (Table 4). This result is similar to that of a previous study which stated that applying two or three irrigations (80–200 mm) to wheat increased crop grain yields by 36 to 450% and produced similar or even higher grain yields than in fully irrigated [6]. Seasonal irrigation water amounts required for nonstressed production varied by year from 390 to 575 mm [19]. Even a single irrigation omission during one of the sensitive growth stages caused up to 40% grain yield losses during dry years [18].

Over years result shown for cool planting period in Table 4 indicate that the highest sesame grain yield (1053.89 kg/ha) was obtained from treatment T7 (100% ETc with the

Table 3: Sesame response to deficit irrigation and combined mean yield (kg/ha) over years (from 2013 to 2015) during the main cropping season.

Irrigation depths	Irrigation methods			Mean
	Alternate furrow	Fixed furrow	Conventional furrow	
100% ETc	1519.4[ba]	1723.2[ba]	1717.3[ba]	1653.27[a]
75% ETc	1440.5[b]	1695.0[ba]	1782.8[ba]	1639.43[a]
50% ETc	1570.0[ba]	1532.7[ba]	1846.7[a]	1649.8[a]
Mean	1509.96	1650.3	1782.27	1647.49
CV%		18.07		
R-square		0.90		
$LSD_{0.05}$	Irrigation method **	Irrigation depth NS	Method ∗ depth **	

Table 4: Sesame yield (kg/ha) response to deficit irrigation and combined mean yield over years during the cool cropping season.

Irrigation depths	Irrigation methods			Mean
	Alternate furrow	Fixed furrow	Conventional furrow	
100% ETc	927.46	992.18	1053.89	991.17
75% ETc	995.45	946.90	1132.02	1024.79[a]
50% ETc	1023.59	928.68	1018.20	990.16
Mean	982.166	955.92	1068.04	1002.04
CV%		21.08		
R-square		0.82		
LSD	Irrigation method **	Irrigation depth **	Method ∗ depth **	

Table 5: Sesame yield response to deficit irrigation in kg/ha during the cool cropping season in 2013–2015.

Irrigation depths	Irrigation methods			Mean
	Alternate furrow	Fixed furrow	Conventional furrow	
Yield (kg/ha) response to irrigation amount and methods during the cool cropping season in 2012/13				
100% ETc	438.61	476.54	427.28	447.48
75% ETc	486.35	470.90	427.30	461.52
50% ETc	492.63	442.27	528.55	487.82
Mean	472.53	463.24	461.04	465.61
CV%		14.69		
R-square		0.41		
$LSD_{0.05}$	Irrigation method 164.87	Irrigation depth NS	Method ∗ depth NS	
Yield (kg/ha) response to irrigation amount and methods during the cool cropping season in 2013/14				
100% ETc	1224.0	1197.9	1171.9	1197.93
75% ETc	1145.8	1119.8	1432.3	1232.63
50% ETc	1119.8	1171.9	1276.0	1189.23
Mean	1163.2	1163.2	1293.4	1206.6
CV%		10.79		
R-square		0.67		
$LSD_{0.05}$	Irrigation method NS	Irrigation depth **	Method ∗ depth NS	
Yield (kg/ha) response to irrigation amount and methods during the cool cropping season in 2014/15				
100% ETc	1119.8	1302.1	1562.5	1328.13
75% ETc	1354.2	1250.0	1536.5	1380.23
50% ETc	1458.3	1171.9	1250.0	1293.4
Mean	1310.77	1241.33	1449.67	1333.92
CV%		26.3		
R-square		0.43		
$LSD_{0.05}$	Irrigation method NS	Irrigation depth NS	Method ∗ depth NS	

Table 6: Combined sesame yield and WUE response over years during the cool cropping season.

Treatment	Yield (kg/ha)	WUE (kg/ha-mm)
100% ETc with alternative furrow	1164.215[c]	1.114000[bc]
100% ETc with fixed furrow	1173.464[bc]	1.068000[bc]
100% ETc with conventional furrow	1242.131[abc]	1.654000[a]
50% ETc with alternative furrow	1284.603[abc]	1.166000[b]
50% ETc with fixed furrow	1246.119[abc]	1.121333[bc]
50% ETc with conventional furrow	1170.299[c]	1.230667[b]
75% ETc with alternative furrow	1319.239[abc]	1.203333[bc]
75% ETc with fixed furrow	1392.311[a]	0.994000[c]
75% ETc with conventional furrow	1349.614[ab]	1.555333[a]
CV	1.981372	1.981372
$LSD_{0.05}$	178.0989	0.2159164

conventional application method) and minimum yield (927.46 kg/ha) was attained from treatment T1 (100% ETc with the alternative application method). During this growing season, the amount of irrigation water applied was saved up to 25% with 8.15% yield advantage than full irrigation (100% ETc) as indicated in Table 6. Similar studies on sesame showed that applying two or three irrigations (80–200 mm) produced similar or even higher grain yields than in fully irrigated [20]. Even a single irrigation omission during one of the sensitive growth stages caused up to 40% grain yield losses during dry years [18]. Much greater losses of 66–93% could be expected as a result of prolonged water stress during the development stage for cereal crops like maize [19]. Partial root-zone irrigation is the most popular and effective because many field crops and some woody crops can save irrigation water up to 20 to 30% with or without a minimal impact on crop yield [21]. The application of water below the ET requirements is termed "deficit irrigation" [6, 20].

3.2. Water Use Efficiency. Water use efficiency of 1.65 kg/ha-mm was attained, which was a maximum compared with other treatments, and 39.75% of water was consumed than treatment 8 irrigated with 75% ETC applied using the fixed furrow method during the cool planting season (Table 6). These results indicated the possibilities of considerable saving of water for sesame without any decrease in grain yield, and 0.99 kg/ha-mm water use efficiency was attained by irrigating with 75% ETC using the fixed furrow method. On the other hand, 1.55 kg/ha-mm water use efficiency was attained from treatment 9 in which 75% ETC water was applied to sesame conventionally. However, as compared to 100% ETC applied with the conventional furrow method, nearly 6.06% of water was saved by irrigating 75% ETC with the fixed furrow method (Table 6). Thus, WUE increases with irrigation amount, and water-saving techniques such as deficit level have been improved water use efficiency (WUE) with minimum yield reduction.

4. Conclusion

Deficit irrigation based on growth stages affected the yield of sesame. The irrigation amount of 100% ETc applied with the conventional application method was the indicator of good relationship with the highest yield of sesame. Therefore, deficit irrigation with the conventional furrow application technique is the best practice of water saving for the irrigated agriculture system under semiarid conditions and in similar areas to produce optimum sesame yield.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that the research data and their findings belong to them and their institution EIAR. They declare that they have no conflicts of interest.

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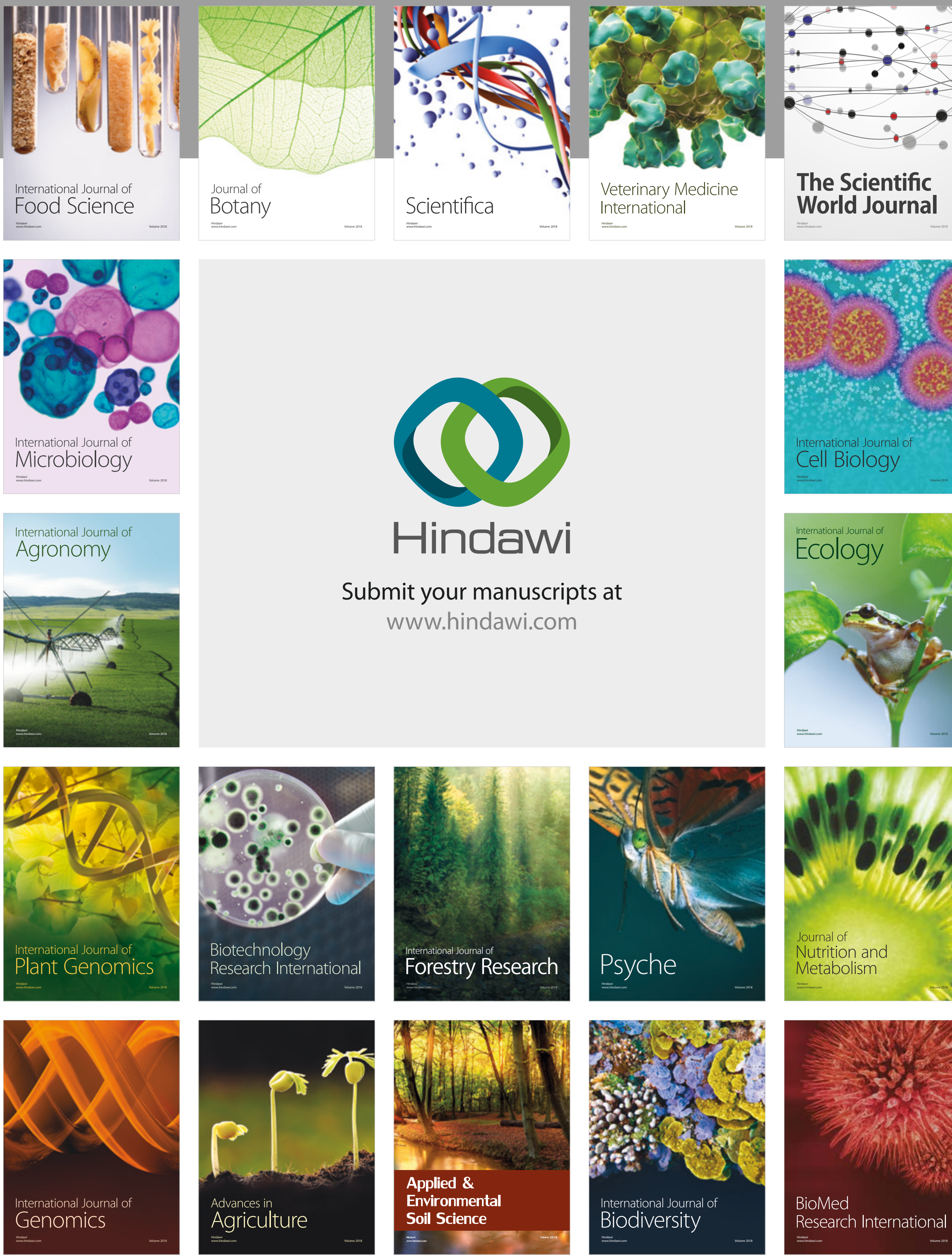
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